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(54) EXPENDABLE TAMPER EVIDENT SECURITY SEAL

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(22) Filed: **Feb. 19, 2010**

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(51) **Int. Cl.**
G08B 13/00 (2006.01)

(52) **U.S. Cl.**
USPC **340/541**; 340/10.1; 340/545.1; 340/572.8

(58) **Field of Classification Search** 340/541, 340/10.1, 545.1, 545.2, 545.6, 545.8, 540, 340/572.1–572.9, 10.5, 568.1; 235/492, 235/487, 493

See application file for complete search history.

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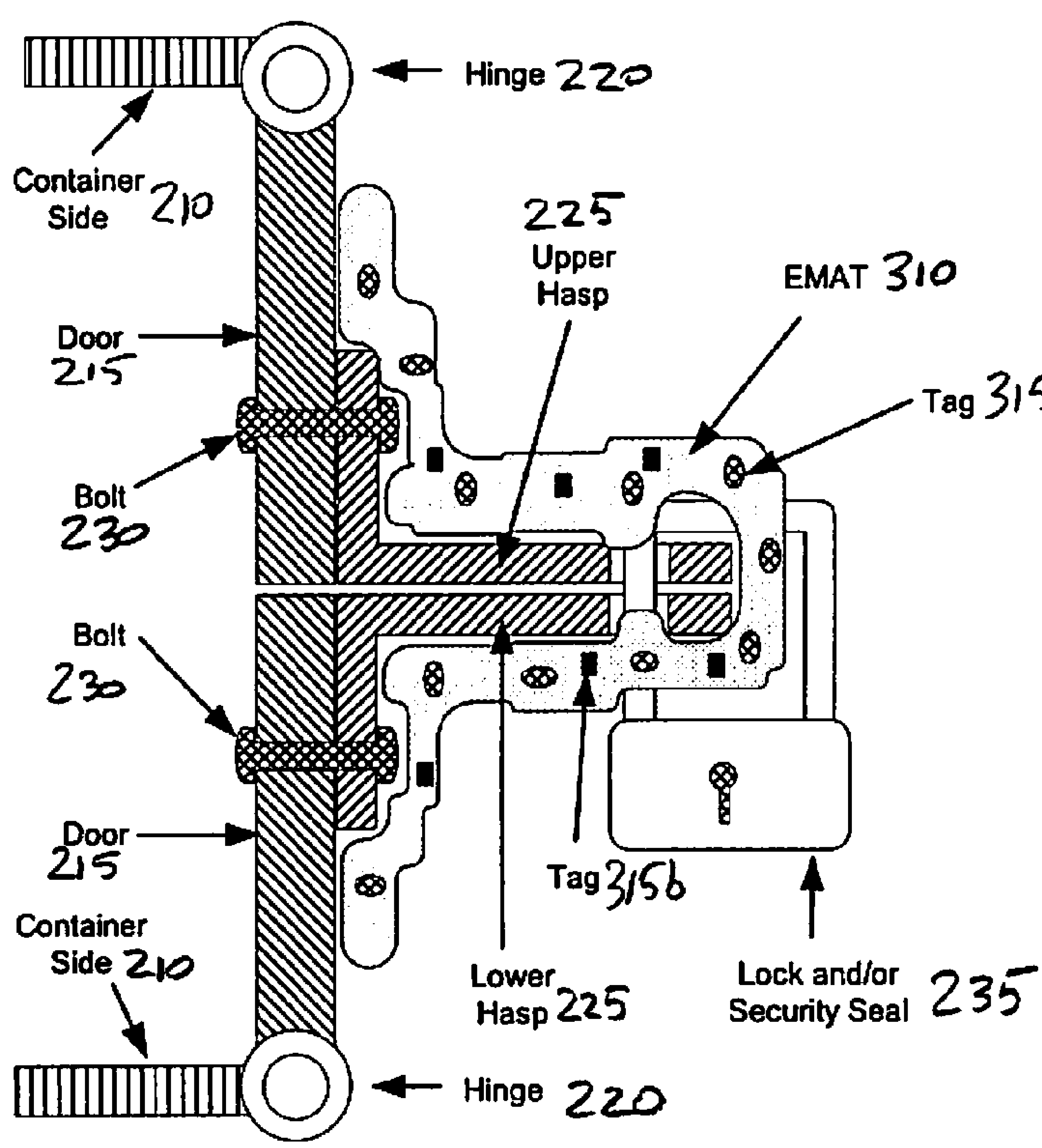
(57) **ABSTRACT**

An expendable tamper evident seal system for monitoring a mechanism to which physical access is required in order to open or close an access-way, comprising: an embedding material moldable into a shape conforming to the mechanism and adapted to be applied to the mechanism; circuit components randomly embedded in the embedding material so as to be arranged in positions and orientations corresponding to the shape, whereby physical access to the mechanism that alters the shape of the embedding material correspondingly alters the positions and orientations of the circuit components in the material; and an electronic interrogation device (EID) including components that induce in the circuit components an electromagnetic spectral response indicative of the position of the EID relative to the positions and orientations of the circuit components in the material, and measure the spectral response.

24 Claims, 10 Drawing Sheets



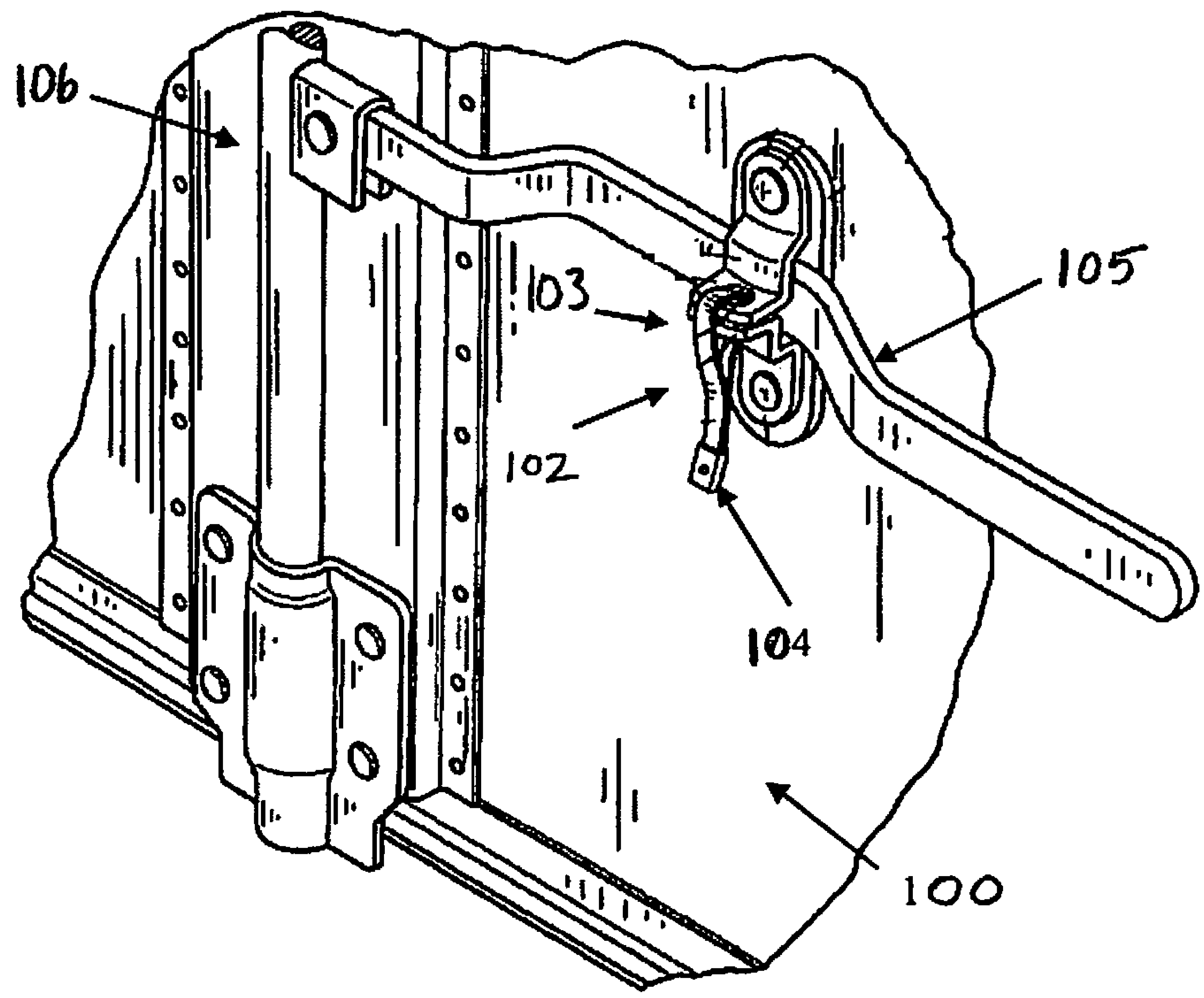


Figure 1 Prior Art

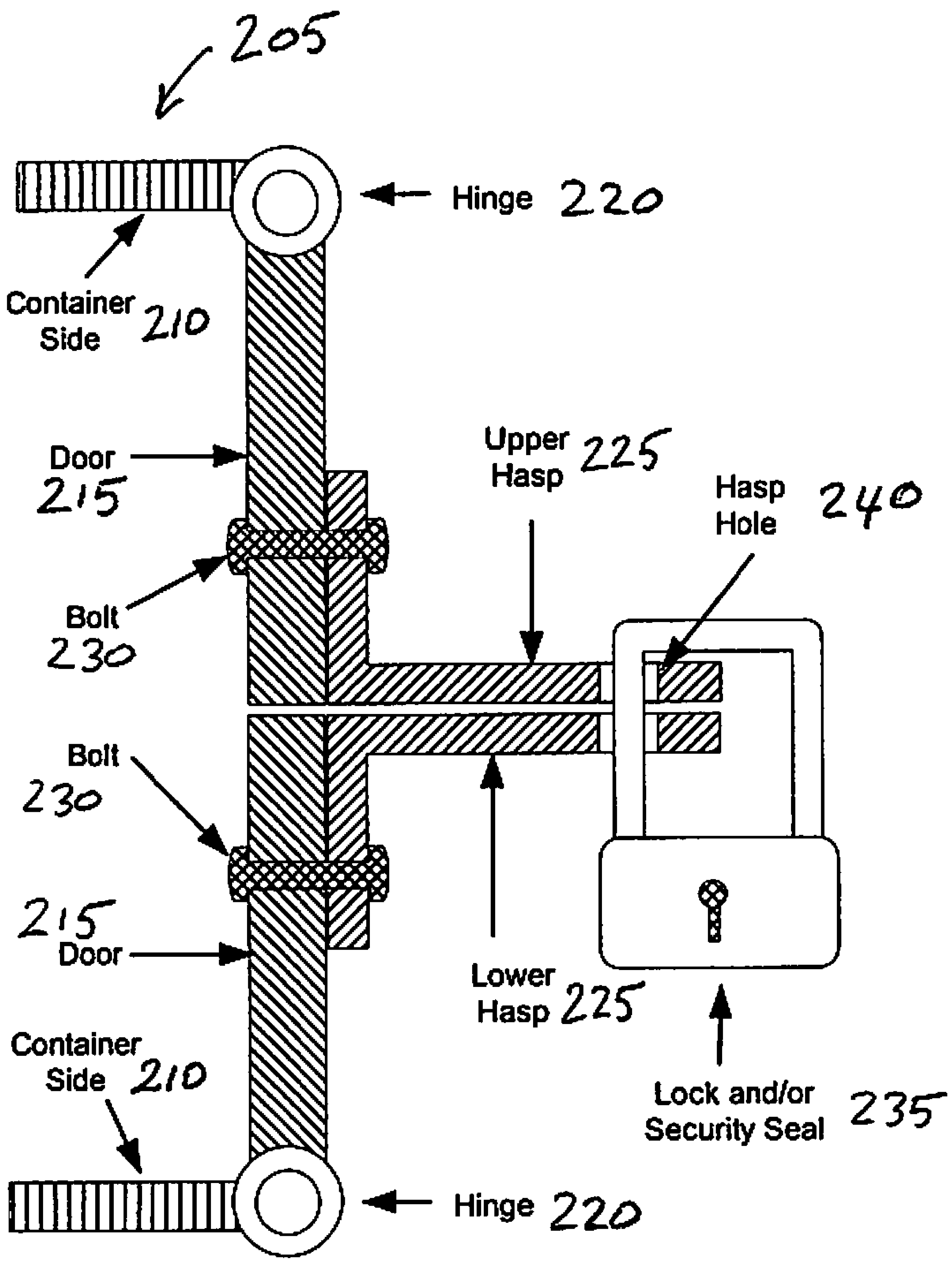


Figure 2 Prior Art

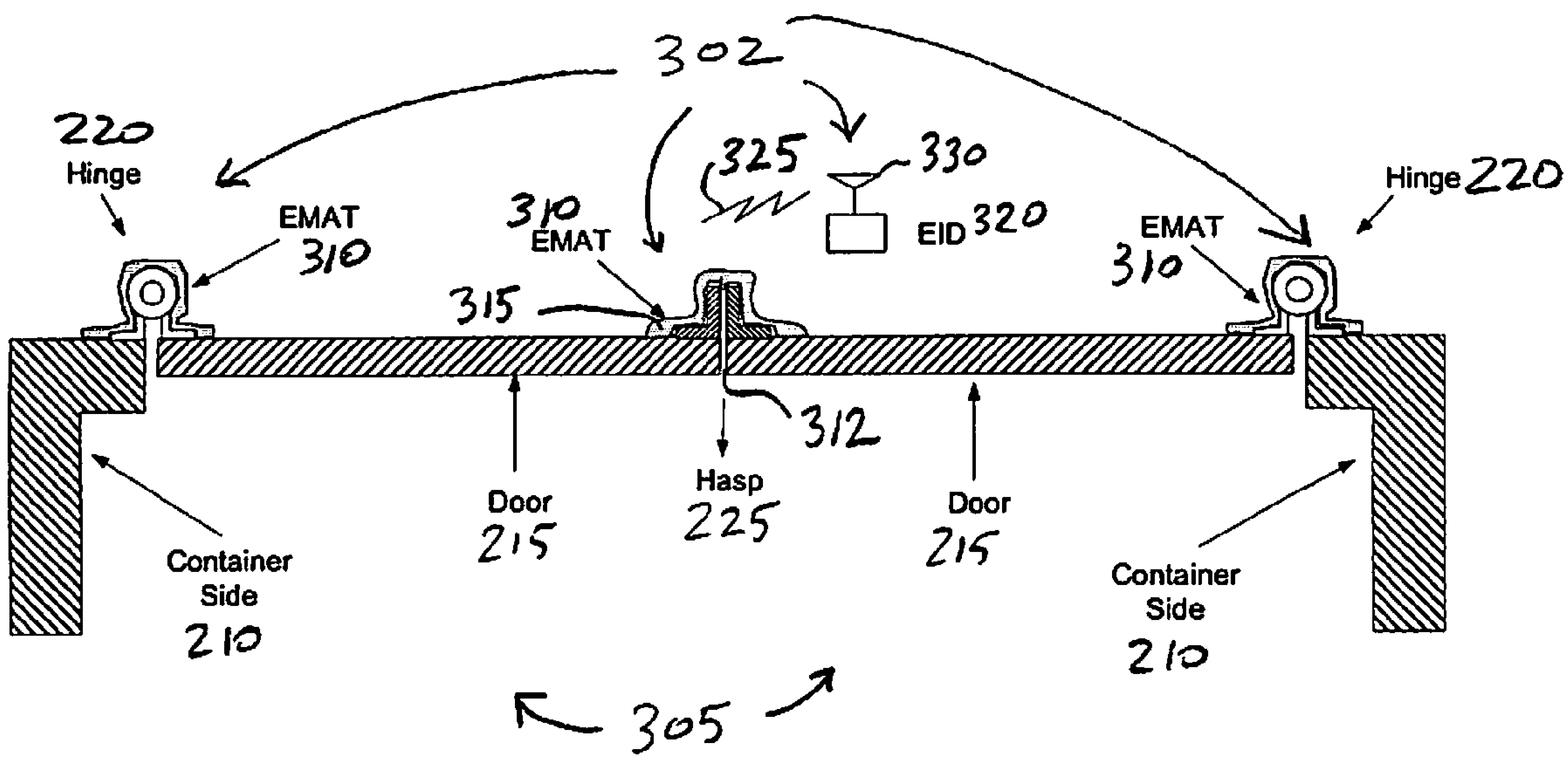
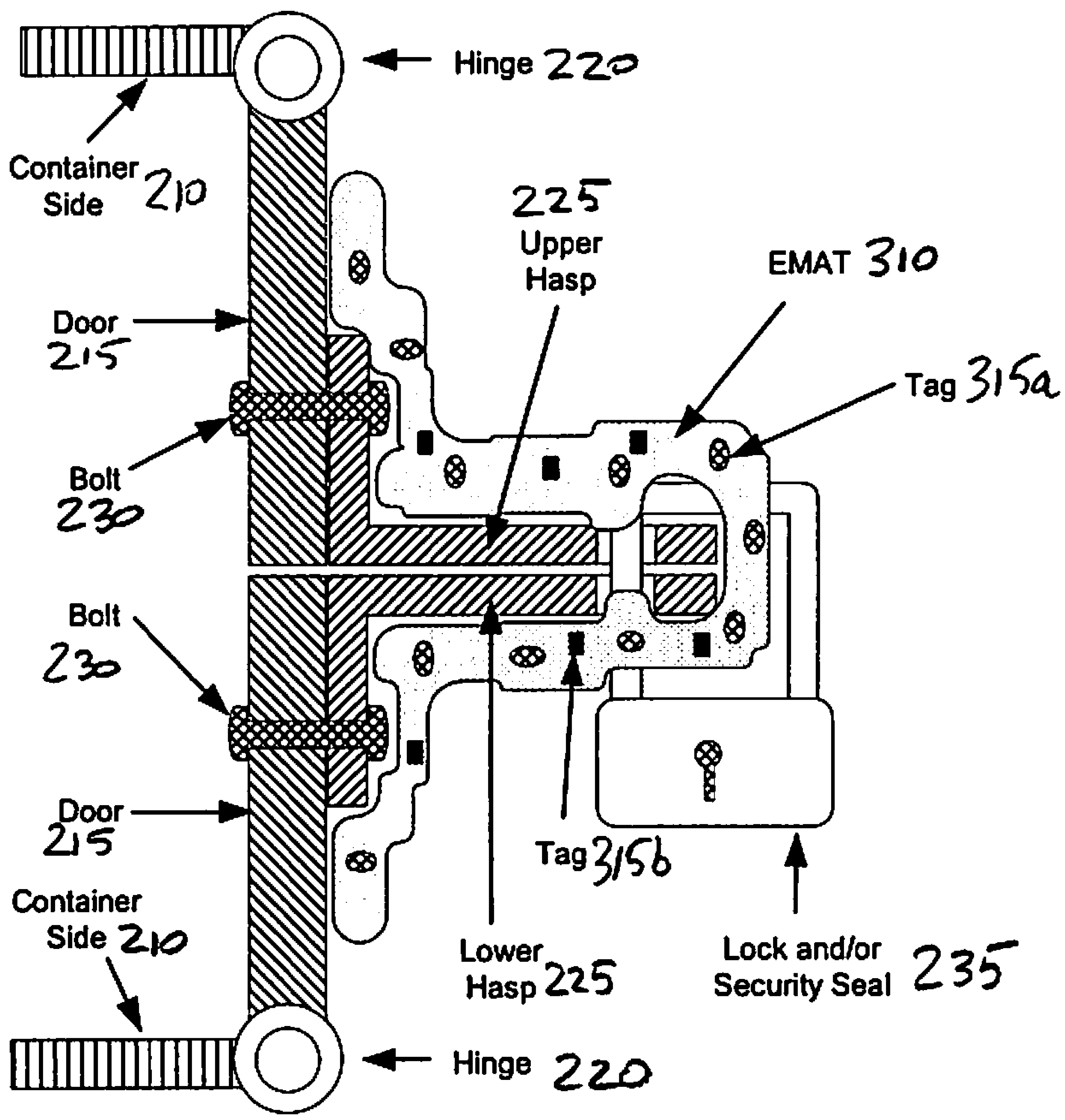

302
220
Hinge
EMAT
310
325
330
310
EMAT
EID 320
EMAT
310
Hinge 220
315
312
Door
215
Hasp
225
Door
215
Container
Side
210
Container
Side
210
305

Figure 3



Hinge 220
Container Side 210
225 Upper Hasp
EMAT 310
Door 215
Tag 315a
Bolt 230
Bolt 230
Door 215
Tag 315b
Container Side 210
Lower Hasp 225
Lock and/or Security Seal 235
Hinge 220

Figure 4

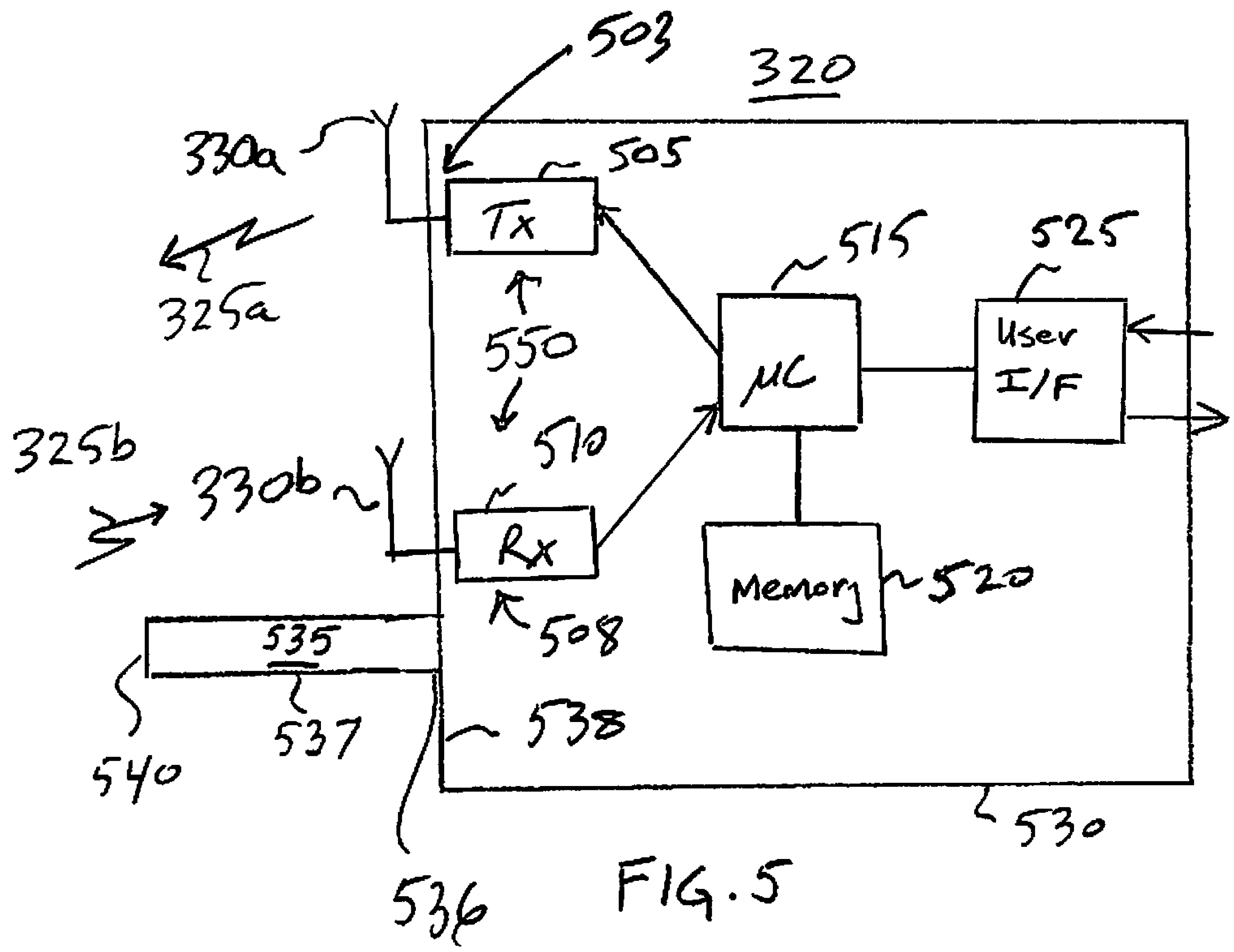
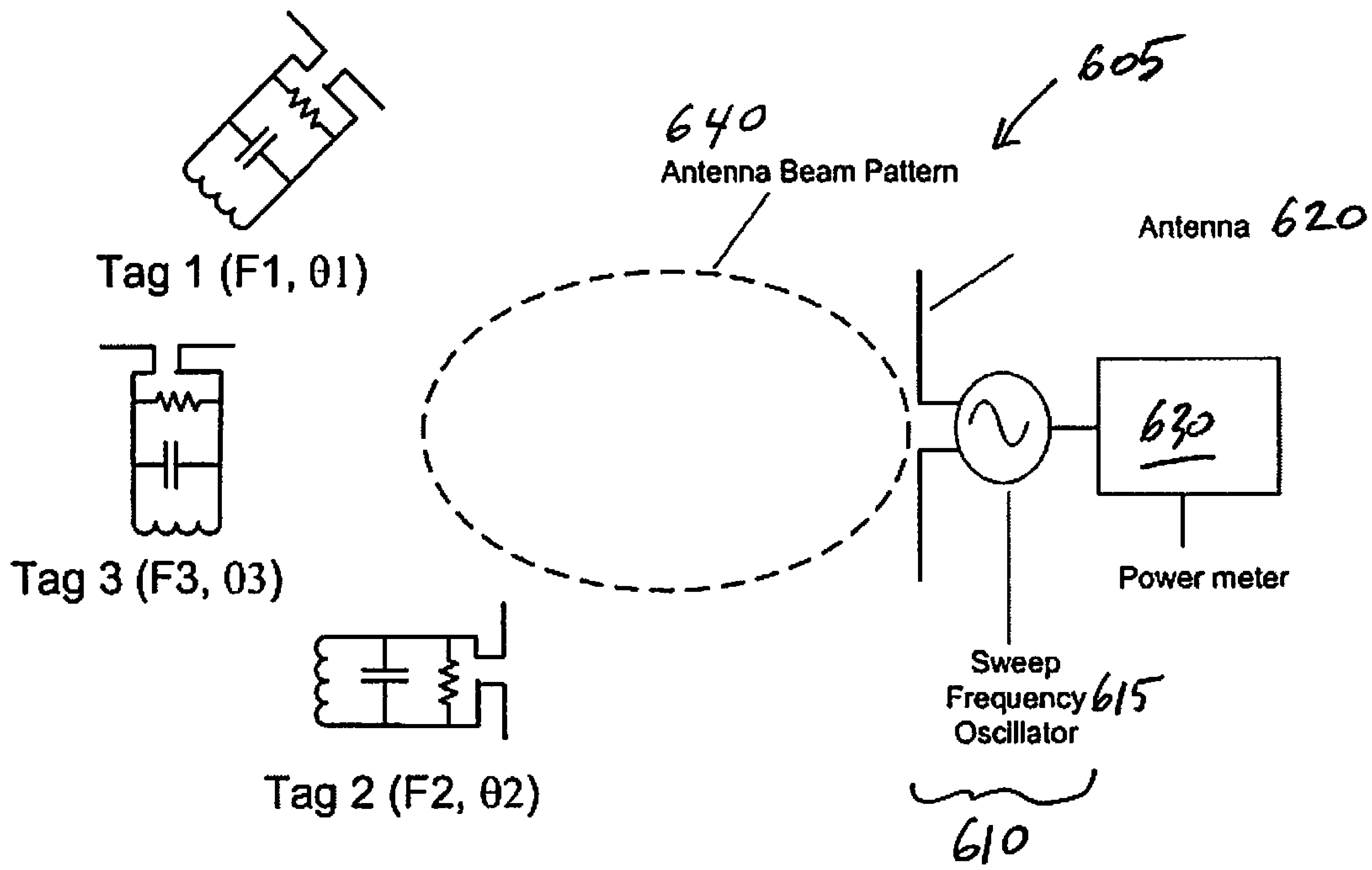

503
320
330a
505
Tx
325a
515
525
550
μC
User I/F
325b
510
330b
Rx
Memory
520
535
508
537
538
540
530
536

FIG. 5



605
640
Antenna Beam Pattern
Antenna 620
Tag 1 (F1, θ1)
Tag 3 (F3, θ3)
Tag 2 (F2, θ2)
630
Power meter
Sweep
Frequency 615
Oscillator
610

Figure 6

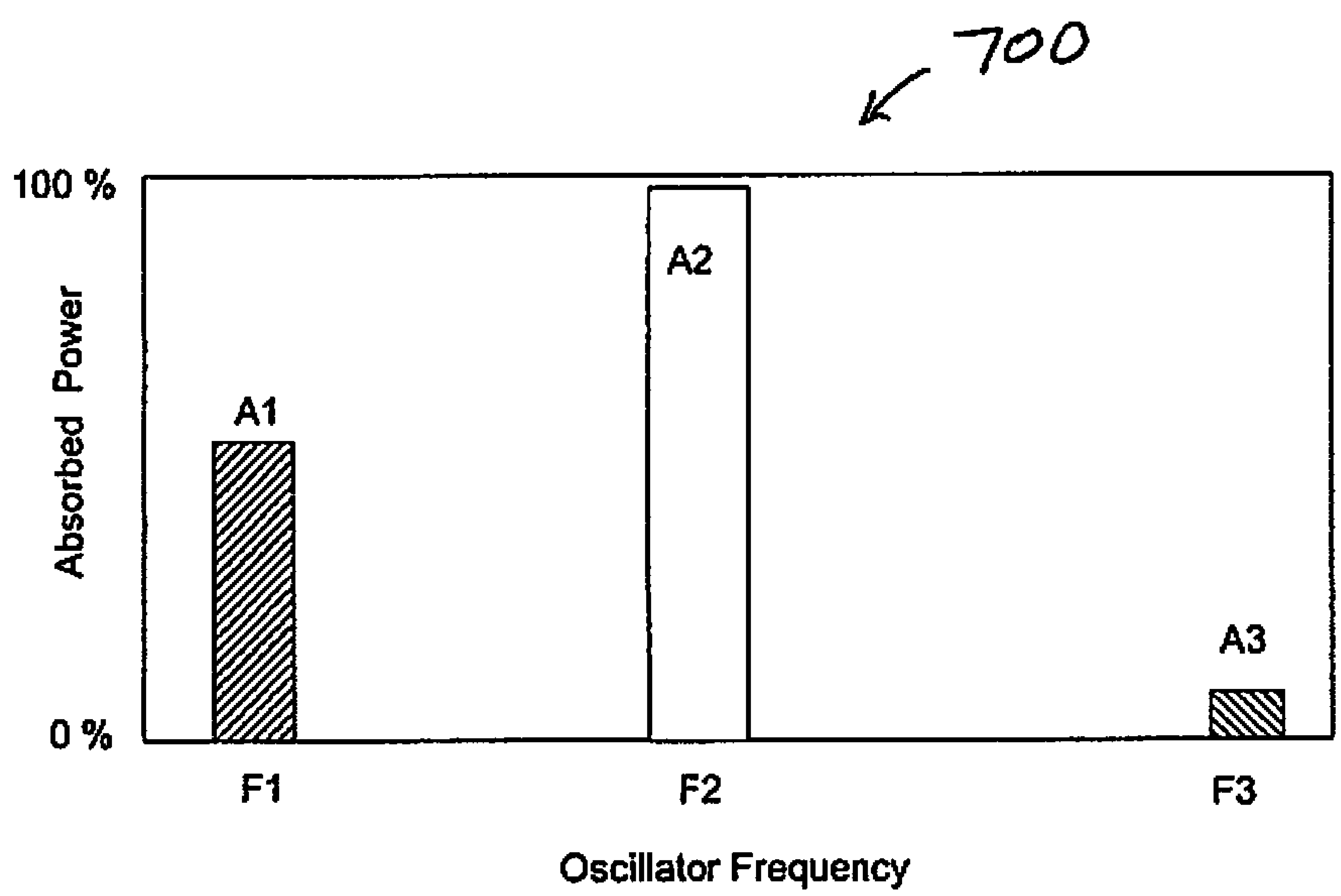

700
100 %
0 %
Absorbed Power
A1
A2
A3
F1
F2
F3
Oscillator Frequency

Figure 7

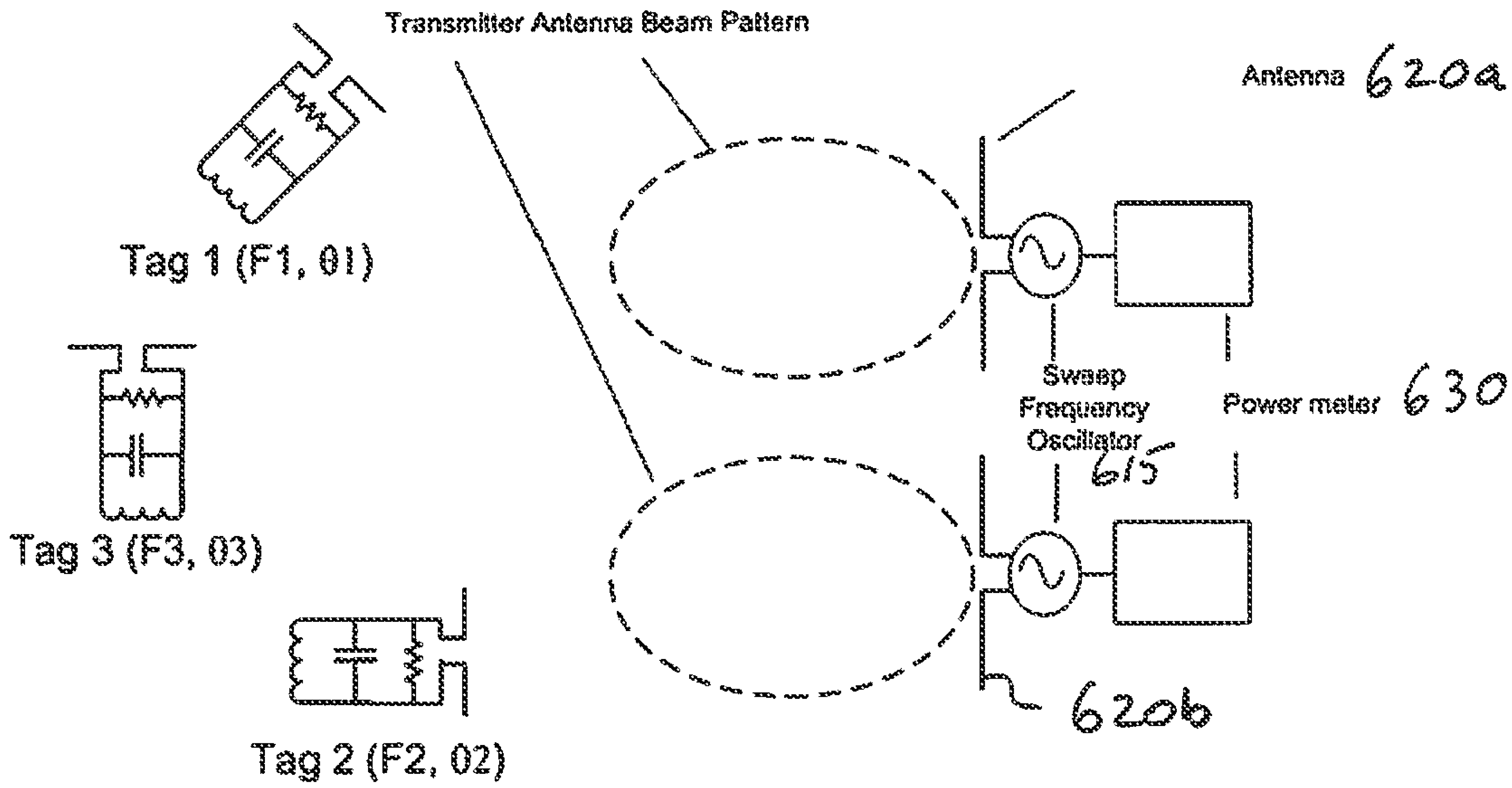


Figure 8

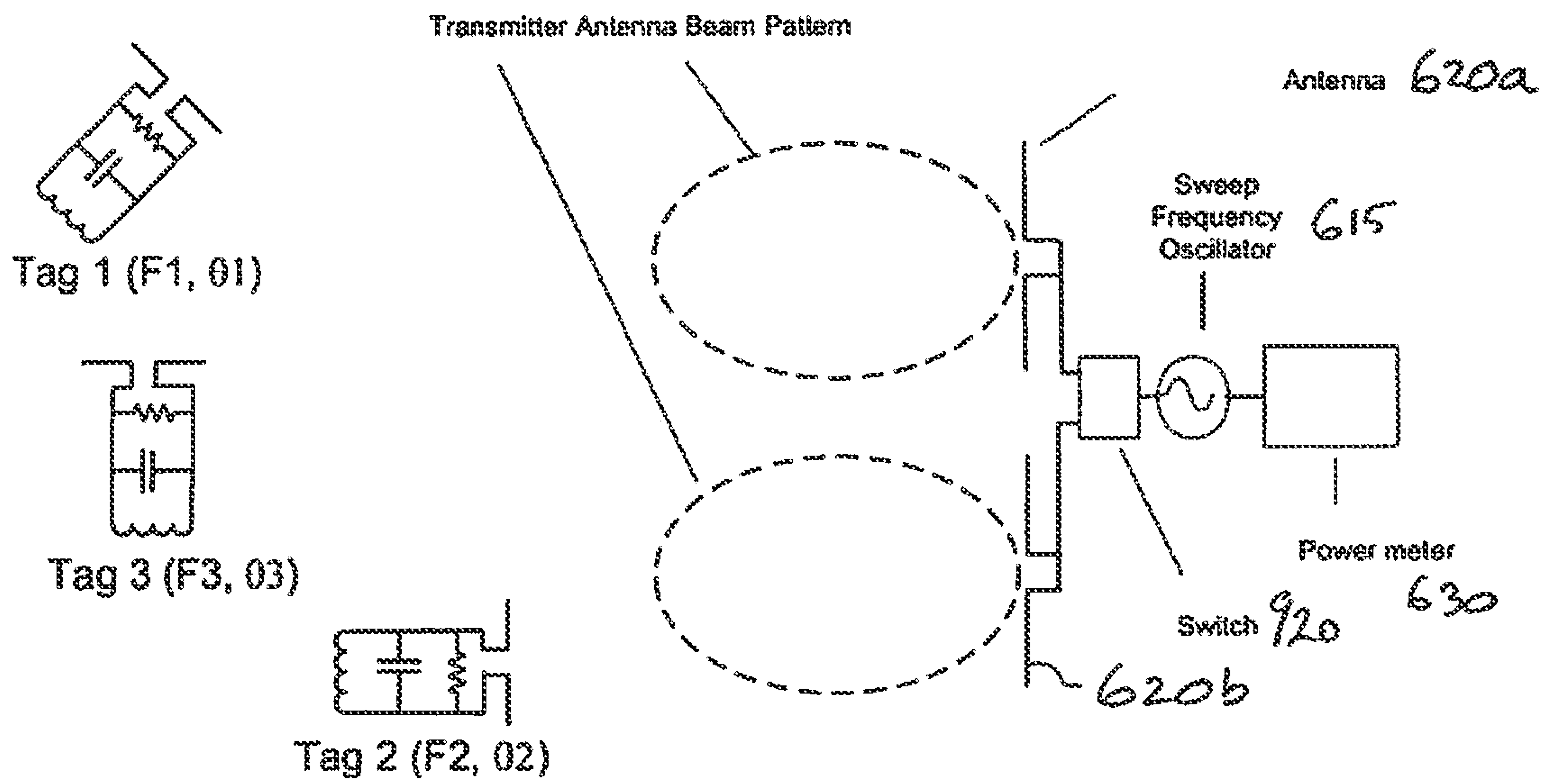


Figure 9

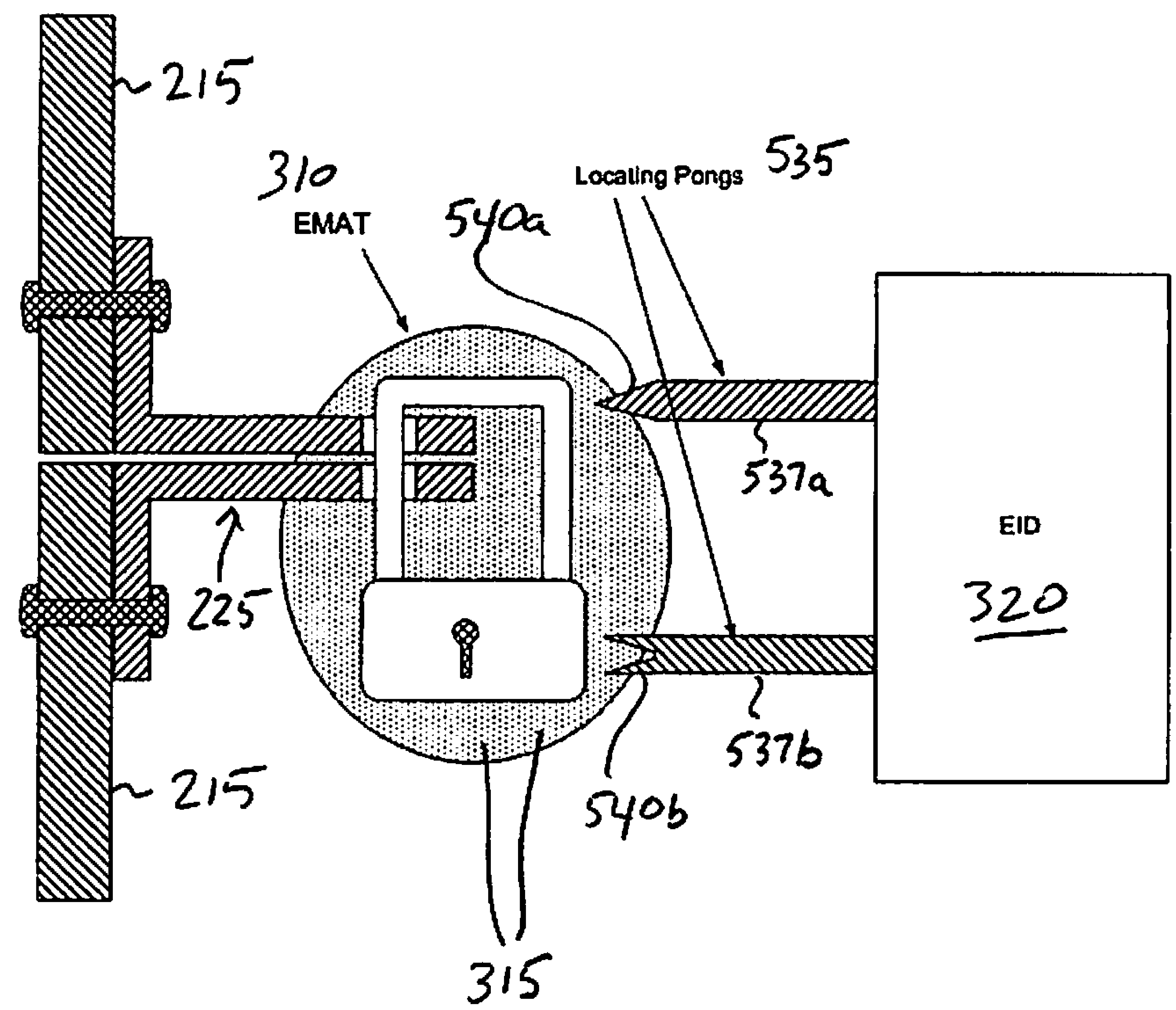

215
310
EMAT
540a
Locating Pongs
535
537a
EID
320
225
537b
540b
215
315

Figure 10

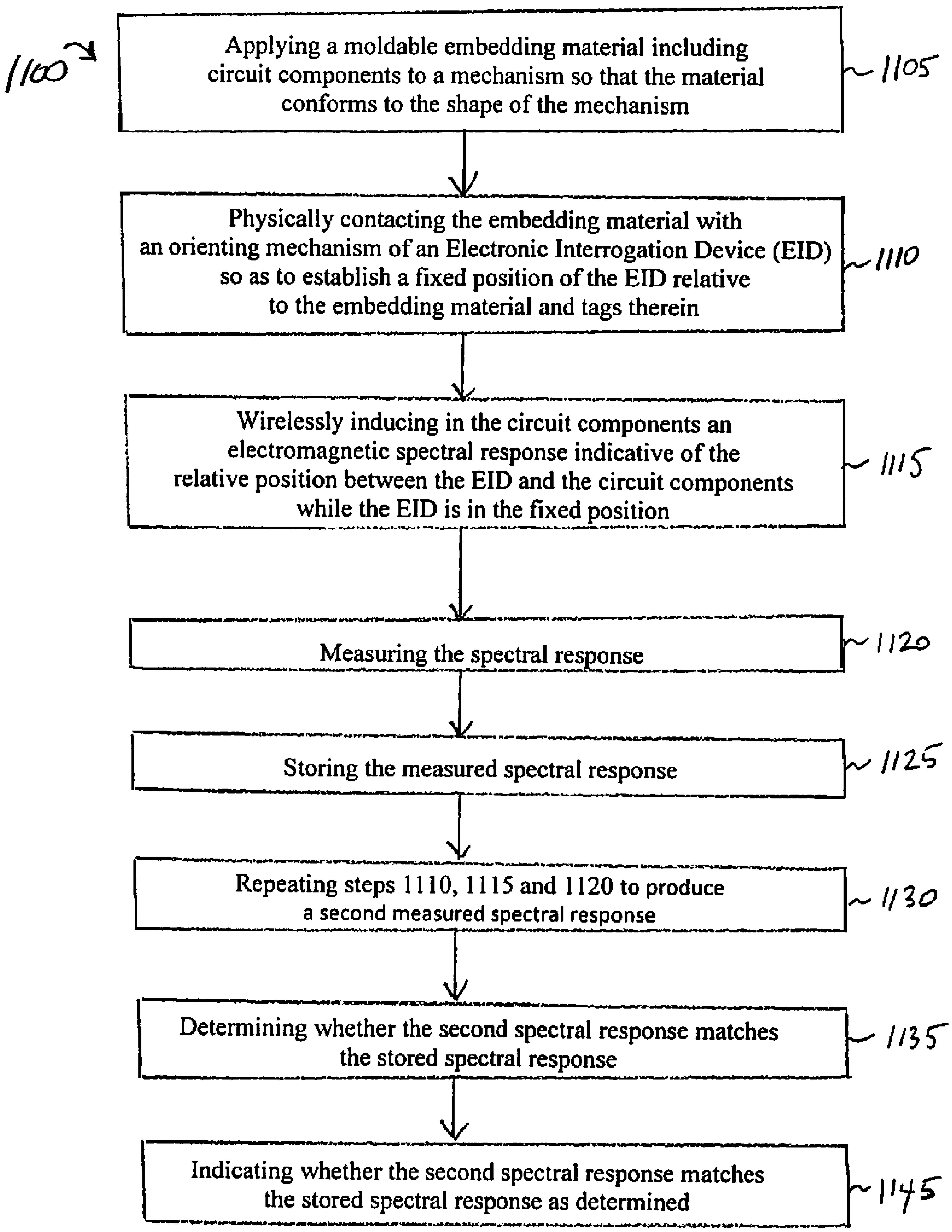

1100
Applying a moldable embedding material including circuit components to a mechanism so that the material conforms to the shape of the mechanism
1105
Physically contacting the embedding material with an orienting mechanism of an Electronic Interrogation Device (EID) so as to establish a fixed position of the EID relative to the embedding material and tags therein
1110
Wirelessly inducing in the circuit components an electromagnetic spectral response indicative of the relative position between the EID and the circuit components while the EID is in the fixed position
1115
Measuring the spectral response
1120
Storing the measured spectral response
1125
Repeating steps 1110, 1115 and 1120 to produce a second measured spectral response
1130
Determining whether the second spectral response matches the stored spectral response
1135
Indicating whether the second spectral response matches the stored spectral response as determined
1145

Figure 11

EXPENDABLE TAMPER EVIDENT SECURITY SEAL

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 61/153,761, filed Feb. 19, 2009, incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The invention relates generally to physical security seals.

BACKGROUND OF THE INVENTION

Approximately 20 million cargo shipping containers are in use throughout the world. Both ship and air transport use cargo shipping containers. With the need for increased security, these shipping containers are typically secured with locks and security seals. Given enough time and the right tools, any locked container can be breached. Modern high security seals do not aim to defeat shipping container break-ins but instead are designed to alert when the container has been compromised, opened or tampered with. These modern seals are called tamper evident security seals (TESS). There are a number of TESS devices on the market, but most are expensive to purchase and when damaged by an intruder are expensive to repair or replace. In the case of a low-cost TESS that uses a wire or other loop-like device to attach itself to a container, the looping device can be by-passed to get access to the container's interior.

For illustrative purposes of prior art a portion of a shipping container cargo door **100** is shown in FIG. **1**. FIG. **1** shows prior art security seal technology **102** which is composed of a simple loop **103** and lock **104**. In addition, FIG. **1** illustrates the complex nature of the shipping container topology with locking handle **105** and rotating locking pin **106**.

FIG. **2** shows a simplified drawing of the prior art hasp and locking technique for a container door. A container **205** includes container sides **210** to which are attached container doors **215** through respective hinges **220**. A hasp **225** (having lower and upper hasps sections) is connected to doors **215** via bolts **230** or other fastening means. Doors **215** are secured with a lock and or security seal **235** passing through hasp holes **240** through the lower and upper hasp sections of hasp **225**.

SUMMARY OF THE INVENTION

The present invention is a low cost, expendable, easy to use TESS designed to be difficult to circumvent. The field of application of the xTESS is not limited to just cargo containers but can be used for securing any type of container. In addition to being used on locks and container/door hasps, the xTESS of the subject invention can be used on hinges or any other complex object including fully encasing the object. A system embodiment of the present invention is a tamper evident seal system for monitoring a mechanism to which physical access is required in order to open or close an access-way, comprising:

an embedding material moldable into a shape conforming to the mechanism and adapted to be applied to the mechanism;

circuit components randomly embedded in the embedding material so as to be arranged in positions and orientations corresponding to the shape, whereby physical access to the mechanism that alters the shape of the embedding material correspondingly alters the positions and orientations of the circuit components in the material; and

an electronic interrogation device (EID) including components that

induce in the circuit components an electromagnetic spectral response indicative of the position of the EID relative to the positions and orientations of the circuit components in the material, and

measure the spectral response.

Other apparatus, system and method embodiments of the present invention will be apparent based on the ensuing description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a prior art security seal.

FIG. **2** shows a prior art locking mechanism.

FIG. **3** is an illustration of an exemplary xTESS system of the present invention used to secure a shipping container.

FIG. **4** shows a close-up simplified block diagram of one embodiment of the system of FIG. **3** in use.

FIG. **5** illustrates an example of an Electronic Interrogation Device (EID) of the present invention.

FIG. **6** is a front-end portion of an EID configured as a grid dip meter (GDM).

FIG. **7** is an model response in Frequency vs. Absorbed power format of the GDM.

FIG. **8** is a block diagram of another embodiment of the EID in the GMD configuration that uses two transmitters and two spatially divergent antennas.

FIG. **9** shows yet another embodiment of the EID in the GMD configuration that uses the two transmitters.

FIG. **10** is an illustration of the EID in a fixed position so as to measure a spectral response of embedded tags.

FIG. **11** is a flowchart of an example method of using the xTESS system.

DETAILED DESCRIPTION OF THE DRAWINGS

The present invention is an expendable tamper evident security seal (xTESS) designed to be inexpensive and difficult to defeat. The xTESS uses electromagnetic sensor technology as a security seal for containers (e.g., cargo containers) and the like to determine whether the containers have been opened or tampered with.

FIG. **3** is an illustration of an exemplary xTESS system **302** of the present invention used to secure a shipping container **305**, depicted in top view. Depicted in FIG. **3** is a top view of cargo container **305** along with the following components of xTESS system **302**:

an embedding material (called the EMAT) **310** that can be molded into shapes and has adhesive properties when attached to a structure (e.g., applied to hasp **225**, doors **215** near the hasp, across a seam **312** between the doors, and hinges **220**);

multiple passive or active electromagnetic components (also referred to herein as "tags," "tag components," "circuit components," or "electronic circuit components") **315** embedded in the embedding material **310** (in FIG. **3**, tags **315** are depicted as small dots in embedding material **310**); and

an electronic interrogation device (EID) **320** that interacts via wireless signals **325** with the tags **315** embedded in the EMAT **310**.

There are a wide range of tags **315** that could embedded in the EMAT **310** and used in the xTESS system **302**, including: passive RFID tags (known in the art), active RFID tags (known in the art), passive resonate antennas, semiconductor components, passive optical materials and passive magnetic materials. The art of passive and active RFID tags is extensive and as will be shown in this document, can be easily adapted as tag components **315** of the xTESS system **102**. Combinations of inductors, resistors, capacitors and semiconductor components (e.g., diodes) connected together to form LR, LC, CR and LRC resonate circuits (which are known in the art) can also be adapted as tag components. Magnetic circuit components with different inductive properties can also be adapted as tag components **315**. Metal and semiconductor material can be tag components. In addition, the tags **315** could be optic in nature (optical tags are also electromagnetic tags operating at much higher frequencies compared to typical RF devices operating at frequencies in the range of GHz). The tags **315** could also be a combination of the above listed components **315**. Many tags **315** are embedded in random positions and three-dimensional orientations within the EMAT **310**, each with a different electromagnetic property indicative of its unique position and orientation.

The EMAT **310** that holds the tags could be a flexible semi-rigid substance like clay, chewing gum, plumbers putty or other similar functional material. The EMAT **310** that holds the tags **315** could also be a rigid substance like epoxy, potting compound (known in the art) or cement or other similar functional material.

The EID **320** includes at least one antenna **330** that transmits a complex signal **325** that interacts with the tags **315** and at least one receiver that measures the interaction of the tags with the transmitted signal. A computing device within the EID measures the xTESS tag response signal (e.g., amplitude, phase and frequency) **325** (also referred to herein as an electromagnetic spectral response) from the multiple random tags **315** embedded in the EMAT **310** and records and documents its complex signal. This tag response signal (or xTESS signature" is then recorded along with the cargo container's unique identification number. Any attempt to remove the EMAT **310** will disturb the tags **315** embedded therein and thereby change the unique electromagnetic signature of the EMAT and tags when the EMAT was originally formed and applied to the structure.

In FIG. **3** the EMAT **310** has been applied not only to the locking hasp **225**, which will be locked via lock or security seal **235**, but also to the hinges **220** of the doors **215** for added security. Note that the soft moldable embedding material of EMAT **310** has been molded into a shape that conforms to the complex topology of the door hasp/lock (**225**, **215**) combination and hinges **310**.

FIG. **4** shows a close-up simplified block diagram of one embodiment of the xTESS EMAT **310** applied to the hasp **225**. Specifically, FIG. **4** shows more details of the EMAT material **310** enveloping the hasp lock **235** and hasp securing bolts **230**. Multiple different types of tags **315***a*, **315***b* are embedded in the EMAT **310**. For clarity, FIG. **4** schematically shows only two different types of tags **315**, however a wide range and a larger number of different types of tags **315** could be embedded in the EMAT **310** and used in the xTESS system **302**.

FIG. **5** illustrates an example of EID **320**. Portions of EID **302** are known in the art by other names and functions. For examples, RFID tag readers are know (e.g., U.S. Pat. No. 7,215,249, incorporated herein by reference in its entirety). EID **320** includes a transmitter **503**, including transmitter components **505** (e.g., amplifier, filter) coupled with antenna **330***a*, that operate together to transmit a wireless signal **325***a* that interacts with the tags **315**, so as to induce in the tags a response signal (also referred to as an electromagnetic spectral response signal or simply spectral response) **325***b* that is indicative of the positions and orientations of the tags. Response signal **325***b* exhibits an amplitude-frequency spectrum unique to the positions and arrangements of tags **315** in EMAT **310**.

EID **320** also includes a receiver **508**, including antenna **330***b* and receiver components **510** (e.g., amplifier, filter and digitizer), for receiving and preprocessing (e.g., amplifying, filtering and digitizing) the induced response signal **325***b*. In an embodiment, antennas **330***a* and **330***b* may be combined into a single transmit-receive antenna. Together, transmitter and receiver **503**, **508** form a transceiver **550** of EID **320** for transceiving wireless signals **325** with tags **315**.

EID **320** also includes a processor **515** that communicates with the other subsystems of the EID to control the EID and both process and store information, measurements and signals. Receiver **508** provides received signal **325***b* to processor **515** in a form on which the processor is able to make amplitude, frequency and phase measurements. Processor **515** is coupled with a memory **520** for storing information and computer code to be executed by the processor in order to perform methods of the present invention. Processor **515** stores into memory **520** received signal **325***b* (as received from receiver **508**) and measurement derived there from.

EID **320** also includes a user interface **525** coupled with processor **515** that includes an indicator, such as a display and/or audible indicator, and an input device, such as a keypad. The input device accepts unique identification numbers, e.g., identifying a specific cargo container, which are stored in memory **520** along with received response signals.

EID **320** also includes a housing **530** for enclosing at least some of the components **505-525**. A physical orienting mechanism, such as at least one physical protuberance, **535** has an end **536** attached to the housing and an elongate portion **537** extending outwardly from the housing, preferably from a side **538** of the housing that is adjacent or next to antennas **330**. An exemplary elongate length of orienting mechanism **535** ranges from a few inches to two feet. Orienting mechanism **535** can be made of any resilient material, such as metal, plastic, and so on. In an embodiment, orienting mechanism **535** is an antenna of EID **320**, such as one of antennas **330**. As will become apparent from the description below, an end portion **540** of orienting mechanism **535** is provided for physically contacting EMAT **310** when the EMAT is applied to a structure (such as a hinge), so as to physically orient EID **320** (and more specifically its antennas **330**) in a fixed position relative to tags **315** in the EMAT. When in this fixed position, EID **320** is located at a fixed distance from the tags **315** and at a fixed relative orientation with respect to the tags.

As will be discussed more fully below, because the spectral response **325***b* is a composite signal that includes many different individual responses from the many different tags **315** embedded in the EMAT **310**, the spectral response forms a unique lock signature associated with the emplaced xTESS EMAT **310**. This unique lock signature (LS) is stored or recorded along with the cargo container's unique identification number (IDN), which may be manually entered into EID **320** via keyboard **525** or entered by an optical or RF scanning technology known in the art from a tag or plaque on the container. The LS and IDN are then used at the time the container is opened to see if the container has been tampered with.

In an embodiment, EID **320** operates in a manner similar to that known in the art as a grid dip meter (GDM) (also known as a grid dip oscillator). In FIG. **6**, there is depicted only a front-end portion **605** of EID **320**. Front-end portion **605** is configured as a GDM that measures a resonant frequency of radio frequency circuits. GDM **605** can be used to measure the amount of radio frequency (RF) electromagnetic field energy absorbed by nearby objects. GDM **605** is coupled with processor **515**, not shown. The GDM is composed of RF transmitter **610** (which, in FIG. **6** encompasses oscillator **615** and antenna **620**, where antenna **620** also serves as a receive antenna), a power source and a means, such as a power meter, **630** to measure the output energy of the RF transmitter. It is known in the art that the RF transmitter energy output changes (decreases) in the vicinity of a resonant circuit which is tuned to the frequency of the oscillator. The nearby resonant circuit of the tags absorbs power from the GDM.

Also depicted in FIG. **6** are three tags TAG **1** (or T**1**), TAG **2** (or T**2**) and TAG **3** (or T**3**) located in two dimensional space near GDM **605**. The three tags T**1**-T**3** are illustrated as small RF dipoles with an LCR circuit that have sharp resonates at three different frequencies (F**1**, F**2** and F**3**), are oriented at three different angles (θ**1**, θ**2** and θ**3**) and are three different distances from the GDM antenna of transmitter **620**. The tags' antennas have an approximate dipole antenna pattern that varies with spatial orientation. The GDM antenna is illustrated as a dipole which also has a spatially varying antenna pattern **640**. The GDM **605** transmits three frequencies, F**1**, F**2** and F**3**. At each frequency the GDM **605**, via meter **630**, measures the amount of absorbed power A**1**-A**3** from the three tags T**1**-T**3** (see FIG. **7**, discussed below). Since the absorbed power from the tags T**1**-T**3** is a function of relative orientation of the transmitter and receiver antenna patterns (of antenna **605**) and the distance between the transmitter and receivers, the absorbed power is different for each tag.

FIG. **7** illustrates an example model response **700**, in Frequency vs. Absorbed power format, from the GDM power meter **630**. T**1** is oriented at a 45° angle relative to the transmitter **620** and therefore has a moderate transmitter to receiver coupling and moderate power absorption A**1**. T**2** is oriented in a direction that is close to maximum coupling between the transmitter and receiver antennas and therefore has a large power absorption A**2**. T**3** is oriented in a direction that has minimum coupling between the transmitter and receiver antennas and therefore has a low power absorption A**3**.

As illustrated in FIG. **7** we can construct a unique combination code from the three frequencies F**1**-F**3** with respective multiple amplitudes A**1**-A**3** for respective tags T**1**-T**3**. As an example, if we assume we have three frequencies with amplitude resolution of 100 we can construct a combination with nearly 160,000 unique codes. Adding a fourth frequency with an amplitude resolution of 100 we can have nearly 4,000,000 unique codes.

In a more realistic and sophisticated GDM system the frequency spectrum is a continuum with frequency broadening. The addition of frequency broadening adds more complexity to the xTESS tags' uniqueness thus enhancing the security of the xTESS coding. In addition, RF phase information from the tags could be measured by the EID to further enhance the signature coding. Techniques for adding more complexity to the xTESS concept is described in the next embodiments.

Another embodiment of the xTESS device uses the same tag arrangement as described above using three different RF resonate tags but now adds more tags so that there are now multiple tags with resonate frequency F**1**, multiple tags at resonate frequency F**2** and multiple tags at resonate frequency F**3**. This arrangement increase the complexity of the response as measured by the GDM. In some cases the different tags with interact with each other and modify the measured amplitude, phase and frequency spectrum.

Another embodiment of the xTESS device uses the same tag arrangement as described above using three different RF resonate tags but now adds small bits of metal that act as reflectors of RF energy. This additional material adds more complexity to the measured response of the GDM which enhances the security of the xTESS device.

Another embodiment of the xTESS device uses the same tag arrangement as described above using three different RF resonate tags but now adds a diode to the circuit. This additional material adds more complexity to the measured response of the GDM by the non-linear nature of the diode excitation. Harmonics of the excitation frequency can now be detected by the receiver thus adding more unique frequencies to the code.

FIG. **8** shows another embodiment of the EID in the GMD configuration that uses two transmitters and two spatially divergent antennas. FIG. **9** shows yet another embodiment of the EID in the GMD configuration that uses the two transmitters, but a single circuit (oscillator) drives the two spatially divergent antennas with the application of a simple switch **920** thus reducing the cost of the EID. With the addition of a second transmitter antenna the number of unique codes from the embedded tags will double because the two antennas are at different spatial positions and orientations relative to the tags. However, this is not the most important feature of adding two or more antennas to the EID.

Consider a counter measure to the xTESS device. A person tries to defeat the xTESS system by using electronic test equipment known in the art and measures the unique xTESS EMAT code. The person breaks the xTESS seal (EMAT) and opens the container. The container now has been compromised. The door of the container is closed and a counterfeit xTESS seal is put in place of the original seal. The counterfeit seal has an electronic circuit (also known as spoofing device) embedded in a counterfeit EMAT. The spoofing device has been programmed to mimic the original signature of the xTESS seal. When the container arrives at its security check point, the EID is used to measure the unique code that was recorded when the container was originally sealed. If the EID uses one antenna in the GDM version of the EID the EID will have difficulty telling the difference between the original and counterfeit seals.

Now consider that the EID uses two antennas. Each antenna records simultaneously a unique RF code from the xTESS seal based on the relative orientation of individual multiple tags with different characteristics (e.g., resonate frequency and antenna orientation). Single or multiple spoofing devices cannot replicate the unique signature seen by the two EID antennas. The spoofing device or devices would need to replicate all of the original tags and the distance and orientation relative to the EID antenna. However, the original xTESS seal was destroyed during the process of opening the container. Adding a third or a fourth antenna, easily done with a switch as shown in FIG. **9**, to the EID would further enhance the security integrity of the xTESS.

Another embodiment of the xTESS device could use active RFID tag technology. In this embodiment the xTESS system would have available a number of different active RFID tags. When the EMAT is manufactured it will contain some of the active RFID tags within the material. The EID would transmit a spectrum of frequencies that would communicate with the RFID tags embedded in the EMAT. The active RFID tag technology could have unique digital code that is unique to the EMAT material.

Note that the EMAT is molded onto the hasp and locking mechanism. To remove the xTESS from the hasp and locking mechanism would require that the EMAT be pulled apart. This would disturb the locations of the tags relative to each other and hence modify the xTESS signature.

Operation of the xTESS System

Operation of the present invention as a security seal is now described. A feature of the present invention that supports such operation is described as follows. As mentioned above, many tags **315** are embedded in random, three-dimensional orientations within the EMAT **310**, each with a different electromagnetic property. Initially, the EMAT **315** can be molded onto (i.e., fixed or applied to) a structure (e.g., the hasp and locking mechanisms **225**, **235**, of a container). The EMAT will conform to the shape of the structure to which it is affixed. As affixed, the EMAT **310** holds the tags in their fixed positions relative to the structure and each other in the conforming shape of the EMAT. Accordingly, the tags will have a unique spectral response corresponding to the initial shape when the tags are interrogated by EID **320**.

Any subsequent physical access to the EMAT **310** (e.g., caused by an attempt to move, remove, or deform the EMAT) that alters the shape of the EMAT **310** will correspondingly alter or disturb the tags **315** embedded in the EMAT and, therefore, correspondingly change the unique electromagnetic spectral response of the tags compared to the response when the EMAT was in the original or initial shape. The change in response is indicative of tampering with the EMAT **310** and structure to which it is affixed. In operational use, it is preferable to induce a spectral response in tags **315** and then measure that response when EID **320** is in a same position that can be repeated time and time again. This is described further in connection with FIG. **10**.

FIG. **10** is an illustration of EID **320** in a fixed position so as to measure a spectral response of tags **315** in EMAT **310**. In FIG. **10**, EMAT **310** is emplaced on a structure, e.g., hasp **225**. It is preferable that there be a unique and repeatable relative orientation reference between EID **320** and EMAT **310** (and tags **315** therein) when an electronic spectral response is induced in tags **315** and then measured by the EID. The embodiment of EID **320** depicted in FIG. **10** includes a pair of prongs **537** as orienting mechanism **535** that help provide a repeatable orientation for multiple measurements taken at different times.

At least one of locating prongs **537** is used to physically contact, e.g., make a physical impression in, the (soft) EMAT **310**. The locating prong holds EID **320** a fixed distance from EMAT **310** and holds the EID at a fixed orientation relative to the EMAT. Preferably, an end **540***b* of the one locating pong has a unique geometry, such as a forked or V shape, that will leave a unique impression in the EMAT, whereby the EID orienting mechanism can be repeatedly placed in that same impression, so as to similarly orient the EID and EMAT relative to each other each time a measurement is taken. Multiple locating pongs **537***a*, **537***b* as shown in FIG. **10** add robustness to the repeatability of the procedure. Note that, as depicted in the embodiment of FIG. **10**, the ends of the two locating pongs **537***a*, **537***b* used for contacting EMAT **310** are different, thus further increasing the repeatability of placing EID **320** in a single orientation relative to the EMAT **310**. The locating prongs can also be used to house the RF antennas as described above.

Method Flow Chart

FIG. **11** is a flowchart of an example method **1100** of using tamper evident seal system **302**.

An initial step **1105** includes applying EMAT **310** to a mechanism (e.g., one or more of hinges, hasps, locks, seams, and doors) to which physical access is required in order to open an access-way (e.g., a door, window, etc.) on a container (e.g., a shipping container). Usually, EMAT **310** would be applied to the mechanism in this step **1105** when the access-way is in its closed position. Therefore, EMAT **310** conforms to the shape of the mechanism to which it is applied and, therefore, tags **315** are arranged in positions and orientations corresponding to that shape.

A next step **1110** includes physically contacting EMAT **310** with end **540** of orienting mechanism **535** of EID **320**, so as to physically orient the EID in a fixed position relative to tags **315** in the EMAT. This positions EID **320** at a fixed distance from, and at a fixed orientation relative to, tags **315**. This contacting step is optional, but preferable for most accurate and repeatable measurement results.

A next step **1115** includes wirelessly inducing in tags **315** an electromagnetic spectral response indicative of the relative position between EID **320** and the tags (and the positions of the tags relative to each other, and thus, the shape of the EMAT) while the EID is in the fixed position. The response exhibits an amplitude-frequency spectrum specific to the current configuration (i.e., shape and locations) of the EMAT. This step includes transmitting from EID **320** wireless signal **325***a* so as to induce the spectral response from tags **315**.

A next step **1120** includes measuring the induced spectral response while EID **320** is in the fixed position. Measured parameters include frequency, amplitude, and, optionally, phase, which together represent a security code (also referred to as a unique signature). This step includes wirelessly receiving the spectral response at EID **320** while the EID is in the fixed position.

A next step **1125** includes storing in memory **520** the measured spectral response and measurements thereof (e.g., frequency and amplitude, and possibly phase) as a baseline measurements. Optionally, a container identification number or other unique marking is inputted to EID **320** and stored therein. Steps **1120** and **1125** are performed using processor **515**.

In the event the seal system **302** is being used to monitor access to a shipping container, after step **1125**, the shipping container is shipped from its current location to a remote destination.

After time has elapsed since step **112**, a next step **1130** includes repeating steps **1110**, **1115** and **1120** to produce a second measured spectral response indicative of the shape of the EMAT **310**. In the shipping container example, this step is performed after the container arrives at its destination, and just before authorized personnel are ready to remove the EMAT so as to open the container.

A next step **1135** includes determining, via processor **515**, whether the spectral response stored in step **1125** matches the second spectral response measured in step **1130**. The determining step includes (i) a direct comparison between the before and after spectral responses, (ii) a comparison between the before (step **1120**) and after (step **1130**) measurements based on the spectral responses, e.g., amplitude, frequency, and, possibly, phase, or (iii) both types of comparisons. A match between the before and after spectral responses indicates that EMAT **320** has not been tampered with in any meaningful way. On the other hand, if the before and after spectral responses do not match, i.e., they are different from each other, then this would indicate that the EMAT has been tampered with.

A next step **1145** includes indicating, via user interface **525**, a result of the determination made in step **1135**, e.g., whether the before and after spectral responses match.

One or more features disclosed herein may be implemented in hardware, software, firmware, and combinations thereof, including discrete and integrated circuit logic, application specific integrated circuit (ASIC) logic, and microcontrollers, and may be implemented as part of a domain-specific integrated circuit package, or a combination of integrated circuit packages. The term software, as used herein, refers to a computer program product including a computer readable medium having computer program logic stored therein to cause a computer system to perform one or more features and/or combinations of features disclosed herein.

Methods and systems are disclosed herein with the aid of functional building blocks illustrating the functions, features, and relationships thereof. At least some of the boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries may be defined so long as the specified functions and relationships thereof are appropriately performed.

One skilled in the art will recognize that these functional building blocks can be implemented by discrete components, application specific integrated circuits, processors executing appropriate software, and combinations thereof.

While various embodiments are disclosed herein, it should be understood that they have been presented by way of example only, and not limitation. It will be apparent to persons skilled in the relevant art that various changes in form and detail may be made therein without departing from the spirit and scope of the methods and systems disclosed herein. Thus, the breadth and scope of the claims should not be limited by any of the exemplary embodiments disclosed herein.

What is claimed is:

1. A tamper evident seal system for monitoring a mechanism to which physical access is required in order to open or close an access-way, comprising:

an embedding material moldable into a shape conforming to the mechanism and adapted to be applied to the mechanism;

circuit components randomly embedded in the embedding material so as to be arranged in positions and orientations corresponding to the shape, whereby physical access to the mechanism that alters the shape of the embedding material correspondingly alters the positions and orientations of the circuit components in the material; and

an electronic interrogation device (EID) including components that

induce in the circuit components an electromagnetic spectral response indicative of the position of the EID relative to the positions and orientations of the circuit components in the material, and

measure the spectral response.

2. The system of claim **1**, wherein the EID includes:

a physical orienting mechanism for physically contacting the embedding material so as to physically orient the EID in a fixed position relative to the circuit components in the embedding material, whereby the induced and measured spectral responses are indicative of the relative position of the EID relative to the circuit components when the EID is in the fixed position.

3. The system of claim **2**, wherein the EID further includes:

a transmitter adapted to transmit a wireless signal that induces in the circuit components the spectral response while the EID is in the fixed position;

a receiver for receiving the spectral response while the EID is in the fixed position, whereby the spectral response is indicative of the relative position between the EID and the circuit components;

a processor for measuring the received spectral response and for processing the measured spectral response; and

an indicator to indicate a result of the processing.

4. The system of claim **3**, wherein the EID further includes a memory for storing the measured spectral response.

5. The system of claim **4**, wherein the EID processor

compares the stored measured spectral response to a current measured spectral response, and

causes the indicator to indicate a result of the comparison.

6. The system of claim **2**, wherein the EID further includes a housing and the orienting mechanism is formed as at least one protuberance from the housing, the protuberance including an end for contacting the embedding material.

7. The system of claim **6**, wherein the orienting mechanism includes two protuberances having ends thereof for simultaneously contacting the embedding material.

8. The system of claim **1**, wherein the fixed position includes a fixed distance and a relative orientation between the EID and the circuit components.

9. The system of claim **1**, wherein the embedding material has an adhesive property by which the embedding material is affixed to the mechanism.

10. The system of claim **1**, wherein the embedding material comprises a semi-rigid clay composition.

11. The system of claim **1**, wherein the circuit components include passive electromagnetic components that exhibit frequency resonances when excited by the wireless signal, such that the spectral response exhibits an amplitude-frequency spectrum indicative of the relative position between the EID and the circuit components.

12. The system of claim **11**, wherein at least some of the circuit components are radio frequency identification (RFID) circuit components.

13. The system of claim **11**, wherein each of the circuit components includes at least an inductor-capacitor (LC) resonant circuit.

14. The system of claim **13**, wherein each of at least some of the circuit components includes an inductor-capacitor-resistor (LCR) resonant circuit.

15. The system of claim **13**, wherein each of at least some of the circuit components includes a diode.

16. The system of claim **1**, wherein the EID further includes at least two antennas for transceiving wireless signals between the EID and the circuit components.

17. The system of claim **1**, wherein the mechanism is one of a hinge, a lock, and a door seam.

18. A method of monitoring a mechanism to which physical access is required in order to open or close an access-way, comprising:

Providing:

an embedding material moldable into a shape conforming to the mechanism and adapted to be applied to the mechanism;

circuit components randomly embedded in the embedding material so as to be arranged in positions and orientations corresponding to the shape, whereby physical access to the mechanism that alters the shape of the embedding material correspondingly alters the different positions and orientations of the circuit components in the material; and

an EID including

a physical orienting mechanism for physically contacting the embedding material so as to physically orient the

EID in a fixed position relative to the circuit components in the embedding material; and

components for transceiving wireless signals with the circuit components;

applying the embedding material to the mechanism when the access-way is closed;

using the EID,

physically contacting the embedding material with the orienting mechanism so as to establish the fixed position of the EID;

wirelessly inducing in the circuit components an electromagnetic spectral response indicative of the relative position between the EID and the circuit components while the EID is in the fixed position;

measuring the spectral response; and

storing the measured spectral response.

19. The method of claim **18**, further comprising, after time has elapsed from said storing step, performing the following using the EID:

physically contacting the embedding material with the orienting mechanism so as to re-establish the fixed position of the EID relative to the circuit components in the embedding material;

wirelessly inducing in the circuit components a second electromagnetic spectral response indicative of the relative position between the EID and the circuit components while the EID is in the re-established fixed position;

measuring the second spectral response indicative of the re-established fixed position; and

determining whether the measured second spectral response matches the stored spectral response.

20. The method of claim **19**, wherein between said steps of storing and physically contacting, the method further comprises shipping a structure on which the access-way resides from one physical location to another.

21. The method of claim **19**, further comprising:

providing an indication of whether the second spectral response matches the stored spectral response.

22. The method of claim **19**, wherein the spectral responses are amplitude-frequency spectrums.

23. The method of claim **18**, wherein the applying step includes applying the embedding material to at least one of a hinge, a seam in a door of the access way, and a lock on a door of the access way.

24. The method of claim **18**, wherein the access-way is a door and the mechanism is one of a hinge, lock and door seam.

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